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(54) Title: MULTICARRIER PILOT ALLOCATOR
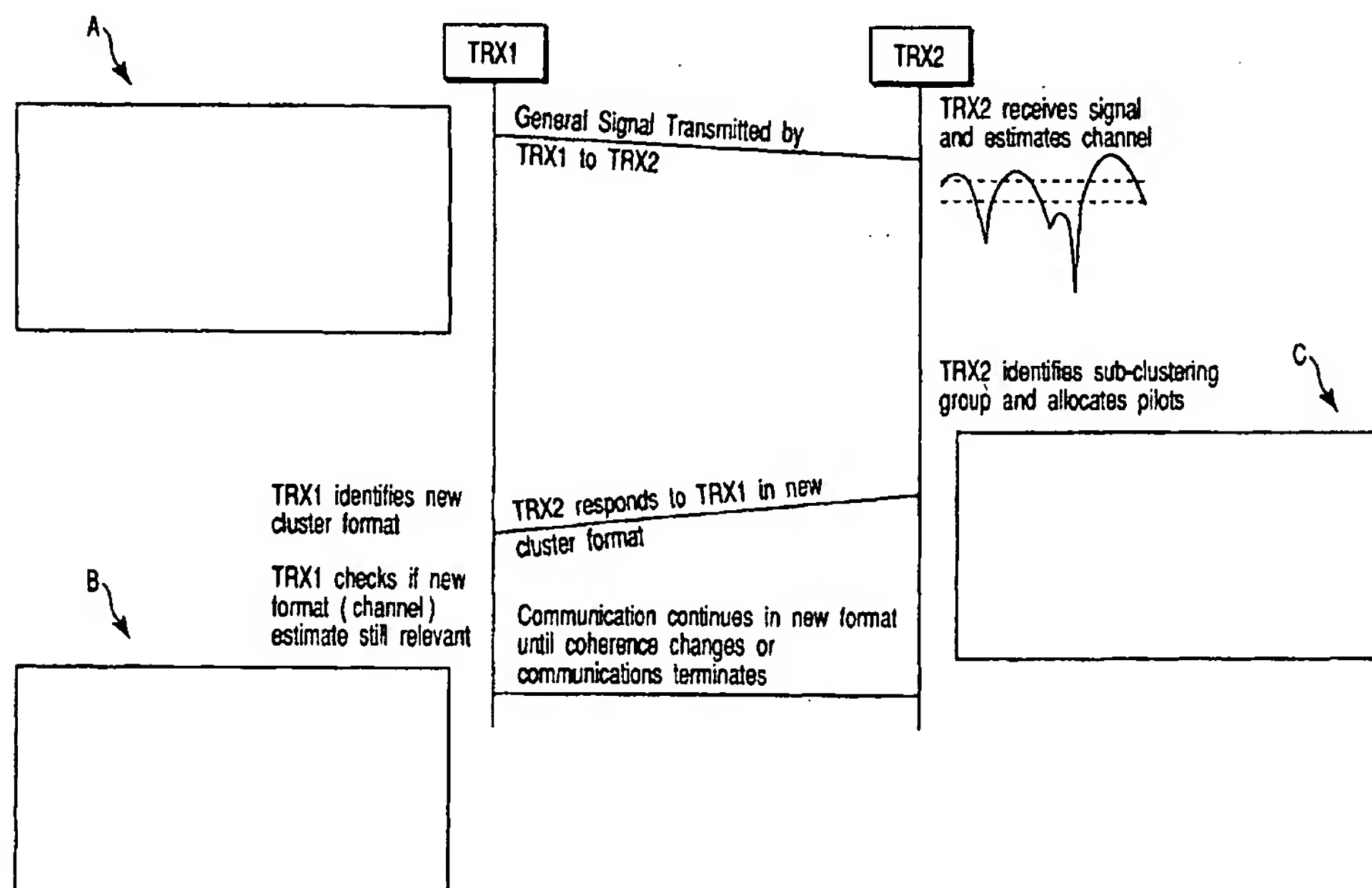
(57) Abstract: The invention provides a system for analyzing a signal received over a channel to determine the channel characteristics. The determined characteristics are then used to divide the sub-carriers up into groups with similar fading characteristics and allocating a pilot channel to each group. The determined pilot allocation scheme is then used for future transmissions across the channel.

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D E S C R I P T I O N

MULTICARRIER PILOT ALLOCATOR

5   Technical Field

The present invention relates to a multi-carrier
or Orthogonal Frequency Division Multiplexing (OFDM)
system employing multiple antennas. In particular, the
present invention relates to the dynamic allocation of

10   pilot carriers.

Background Art

There are now a number of systems which operate at
high data rates such as multi-media applications like
Wireless Local Area Network (WLAN); Wireless Personal

15   Area Network (WPAN), e.g. Bluetooth; etc. Various
arrangements have been proposed in order to facilitate
such high data rates in a reliable and practical way.
However, there are a number of problems associated with
high data rate wireless channels, particularly due to

20   multipath. This is especially problematic indoors
where the environment is particularly dispersive due to
the large number of objects and surfaces as well as the
dynamic nature of structures, particularly people,
moving about. Consequently, it can be extremely

25   difficult to extract and retrieve the original
information from a transmitted signal reliably and
without extremely complex processing. This results in

complex receivers which must be capable of estimating

and compensating for the multiple versions of the

original signal arriving at the receiver due to the

different path length of each version.

5   In order to counter this, a multi-carrier approach

has been proposed in which the original data stream is

separated into a series of parallel data streams, each

of which is modulated and transmitted with a different

frequency, generally within the same band. This allows

10   the relative size of the transmitted symbols relative

to the multipath delay to be much larger and so inter

symbol interference is reduced. One particularly

advantageous system, which utilizes multiple carriers

is Orthogonal Frequency Division Multiplexing (OFDM).

15   OFDM is very effective at overcoming the problems

of fading and multipath. This is achieved by dividing

a frequency selective fading channel (i.e. a channel

where the fading characteristics at one frequency are

likely to be different to those at neighboring

20   frequencies such that the profile of the received

signal against frequency is not flat) into a number of

flat fading sub-bands. In this way, the profile within

the sub-bands is approximately flat. These sub-bands

relate to the OFDM sub-carrier frequencies.

25   FIG. 1 shows an example of the layout of a

transmitter 10 and receiver 20 for an OFDM system.

In the multi-antenna receiving unit 21, each of the

antennas receives a signal, which is fed to an analogue
to digital converter 22 and then into a serial to
parallel converter 23 to separate the individual sub-
channels. The sub channels are then processed through
a Fast Fourier Transform (FFT) 24. Finally, the
signals are converted from a plurality of parallel
signals into a serial signal for each sub-channel and
the coded data extracted.

In such an OFDM receiver system, it is possible to
apply adaptive beamforming weights at various points in
a receiver as shown in FIG. 1. However, the
effectiveness of these weightings will largely depend
on the stability and coherency of the propagation
channel. If the channel undergoes flat fading (i.e.
the signal strength of each of the sub-carriers is
affected to the same extent), then it can be regarded
as being a narrowband channel. In this case, a single
set of weights can be applied at radio frequency (RF)
or intermediate frequency (IF), to the received signal
just after the antenna array 21, i.e. at position (1)
in FIG. 1. Alternatively, the weights may be applied
after the analogue to digital unit 22 at position (2)
in FIG. 1. Both of these positions should be
sufficient for optimum spatial processing.

However, in wideband systems, operating at high
data rates such as WLAN, WPAN, etc., where bandwidths
of 10 MHz or higher may be required and/or systems

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operating in highly dispersive environments, signals
will occupy a spectrum in excess of the coherence
bandwidth. Consequently, there will be significant
variation in the quality/signal strength of the

5   channels across the bandwidth. Consequently, it is
unlikely that a single set of weights (i.e. as in
narrowband beamforming) would be satisfactory for
beamforming.

One way to overcome this problem is to process

10   the received data and apply weightings in the receiver
for each sub-carrier, after the FFT 24, i.e. at
position (3). FIG. 2 shows an example of a receiver.
In this system, the signal is received by antennas
101,102,103. Pre-processing units 104,105,106, carry

15   out downconversion, A to D conversion, serial to
parallel conversion and FFT processing. The outputs
are then fed into an array of adaptive signal
processing devices 107,108,109 which include a
plurality of multipliers 110 which multiply each of the

20   received signals by a weighting value w determined by a
weight determining unit 113. Each of the weighted
signals from the multipliers is then summed 111 to
provide an output signal. The output signals from each
of the weighting units is then fed to a combining unit

25   112 which extracts a data signal in which the delayed
signals and interference signals have been removed from
the received signal.

However, in the example shown, the receiver has L
antennas and the number of sub-channels that each
antenna receives is N. Therefore, the totoal number of
weighting units required is $L \times N$. This can lead to a

5   very large number of multipliers 110 being required.
For example, in the HIPERLAN system, there are 48 data
sub-carriers and 4 pilot sub-carriers (N=52); there is
also a DC channel (CH0) which does not carry data.
This means that the receiver is complicated and this

10   results in the receiver being expensive and potentially
subject to reliability problems. In addition, the
weighting is normally implemented in software and so
processor demand is extremely high, again resulting in
high expense or poor performance. If the processing to

15   determine the weighting to be applied is unduly
complex, then it may take a significant amount of time
to complete. During this time, the channel parameters
may have changed significantly and so the calculated
weightings could be inappropriate. Under these

20   circumstances, the weighting produced would always out
of date and hence poor performance will result where
the characteristics of the channel change rapidly with
time.

One way to reduce the processor demand, is to

25   divide the operating bandwidth into a number of
sub-bands and then select one sub-carrier from within
each sub-band on which to base all calculations.

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This method relies upon each sub-band behaving
generally as a narrowband, i.e. that the sub-band
effectively undergoes flat fading. In other words the
chosen sub-carrier is accurately representative of the
5   fade within the sub-band as a whole. However, without
prior knowledge of the operational environment, it is
difficult to know to what extent the operating band
should be divided up. Where large sub-bands are chosen
there is a danger that the chosen sub-carrier would not
10   be sufficiently representative of the sub-band and
performance would be degraded. In contrast, if the
number of sub-bands is chosen to be large (i.e. few
carriers per sub-band), whilst the representative sub-
carrier is likely to be accurately representative of
15   the sub-band, the amount of processing required is
disadvantageously high.

EP-A2-0,852,407, which relates to current
standards for 5 GHz WLANs, suggests reducing the total
number of adaptive signal processing units and hence
20   the number of weighting units to improve the receivers
by reducing the complexity. The document describes
dividing the operating band into four equal sub-bands
each having a 'pilot' sub-carrier.

Providing pilot sub-carriers at equal intervals
25   amongst the sub-carriers allows the receiver to
calculate the average and differential carrier phase
errors. This is achieved by knowing the form of the

pilots. Using this information, the receiver can fine-tune the carrier and timing tracking circuits such that errors are minimized.

An example of this arrangement is shown in FIG. 3
5   where the operating band is divided into fifty-three
channels or sub-carriers (i.e. as in HIPERLAN), these
are then divided up into four separate groups each
defining a sub-band. Each sub-band includes a sub-carrier, which acts as a pilot for the group (in the
10   example, channels-21, -7, 7 and 21). The pilot
channels do not carry signal data but contain a
predetermined sequence for use in equalizing the
received signal by comparing the received signal to an
expected signal. Weighting for the received signals is
15   determined using the pilot sub-carriers and is then
applied to each sub-carrier in the respective sub-band.
As indicated above this system relies upon flat fading
over each sub-band, which in the case of the above
referenced document are of the order of 5 MHz in size.

20   To aid the coherent demodulation process for OFDM
systems, pilot sub-carriers are interspersed between
the data sub-carriers at equal intervals. Knowing the
form of these pilots, it is possible to calculate the
average and differential carrier phase errors, which
25   can in turn be used to fine-tune the carrier and timing
tracking circuits in the receiver, such that any errors
are minimized.

If the bandwidth of the system is increased such that the sub-bands have considerably greater band width, for example in the region of 10 MHz, then the likelihood that the sub-bands will have flat fading is

5   considerably reduced, particularly where the environment is such as to give strong multipath interference, e.g. indoors. Consequently, the pilot is less likely to provide an accurate indicator for the sub-carriers in the sub-band.

10   Dynamic allocation of the modulation scheme of sub-carriers has been proposed, for example the Atheros system, to extend the basis of 5 GHz systems to allow a wide range of devices to coexist under a unified protocol. In this way, individual sub-carriers are

15   allocated a modulation scheme according to the existing conditions. In the Atheros system, the highest order modulation scheme possible is allocated to each sub-carrier to maximize throughput. If some of the sub-carriers are experiencing more severe fading, then

20   a lower order modulation scheme can be applied. This reduces the potential throughput but provides a more reliable transfer and so the valid data throughput is maximized.

A further problem associated with this arrangement

25   is that if a pilot channel falls in a frequency slot that is experiencing severe fading, the pilot may be unrecoverable and cannot be used in the calculation of

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the average and differential carrier phase errors.
Consequently, a large portion of the band may become
unrecoverable due to the reduced estimation and
interpolation between the remaining pilots. FIG. 4

5   shows an example of a dispersive channel based upon the
ETSI 5 GHz HIPERLAN/2 channel models, indicating the
approximate spacing and locations of pilots. Of the
four pilots, one of the pilots is in a deep fade.
Consequently, the receiver may not be able to recover

10 the pilot and therefore the group of channels that rely
upon the information from this pilot may also be
unrecoverable. Referring back to FIG. 3, it will be
apparent that the sub-carriers in group 3 would be
unrecoverable due to the loss of the pilot in

15 channel 7.

        Application number GBQ108026.6 describes a system
for rearranging the sub-bands according to the channel
characteristics. In this way, the sub-carriers can be
dynamically allocated to sub-bands so that all the sub-

20 carriers within a sub-band have similar coherency
within a limited period of time.

                    Disclosure of Invention
        The present invention can be implemented either in
hardware or on software in a general purpose computer.

25 Further the present invention can be implemented in a
combination of hardware and software. The present
invention can also be implemented by a single

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processing apparatus or a distributed network of
processing apparatuses. Since the present invention
can be implemented by software, the present invention
encompasses computer code provided to a general purpose

5   computer on any suitable carrier medium. The carrier
medium can comprise any storage medium such as a floppy
disk, a CD ROM, a magnetic device or a programmable
memory device, or any transient medium such as any
signal e.g. an electrical, optical or microwave signal.

10   Therefore according to the present invention there
is provided a terminal for use with a multi-carrier
communication system, the terminal comprising: a pilot
allocator for determining pilot allocation information
based upon the characteristics of a channel over which

15   a signal is to be transmitted; and a transmitter for
transmitting a multi-carrier signal comprising a
plurality of sub-carriers wherein one or more of the
sub-carriers are allocated as pilot channels based upon
the pilot allocation information.

20   The present invention further provides a terminal
for use with a multi-carrier communication system, the
terminal comprising: a receiver for receiver for
receiving a multi-carrier signal comprising a plurality
of sub-carriers transmitted over a channel; an analyzer

25   for analyzing the received signal to determine the
channel characteristics; and a pilot allocator for
using the channel characteristics to determine pilot

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allocation information identifying one or more of the
sub-carriers to be allocated as pilot channels.

The present invention also provides a method of
communication in a multi-carrier communication system
5   comprising: determining pilot allocation information
based upon the characteristics of a channel over which
a signal is to be transmitted; and transmitting a
multi-carrier signal comprising a plurality of sub-
carriers wherein one or more of the sub-carriers are
10   allocated as pilot channels based upon the pilot
allocation information.

Furthermore, the present invention also provides a
method of communication in a multi-carrier
communication system comprising: receiving a multi-
15   carrier signal comprising a plurality of sub-carriers
transmitted over a channel; analyzing the received
signal to determine the channel characteristics; and
using the channel characteristics to determine pilot
allocation information identifying one or more of the
20   sub-carriers to be allocated as pilot channels.

The present invention allows a received signal to
be analysed to determine the characteristics of the
channel over which it is transmitted. By doing this,
the pilots can be selectively allocated to channels
25   which will provide a representative indication of the
sub-band which the pilot is acting as pilot to.
Furthermore, where the channel is suffering flat fading

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over a significant number of sub-carriers, the number
of pilots in that region can be reduced. Similarly,
where the response of the channel is variable, the
number of sub-carriers allocated to an individual pilot

5   can be reduced. Thus the pilot can still provide a
reasonably accurate indication of the fewer number of
sub-carriers which it represents.

Furthermore, by avoiding deeply faded channels,
the pilots can almost always be recovered and so the

10   loss of whole groups of sub-carriers, or sub-bands,
because the pilot channel is lost can be avoided.

Furthermore, in the HIPERLAN/2 standard, only four
pilots are allocated. However, by having dynamic pilot
allocation, this number might be reduced where the

15   channel suffers flat fading. Equally, where the
channel is highly dispersive, the number of pilots can
be increased to allow a better indication of how the
channel is affecting all of the sub-carriers. By
varying the number of pilots, the throughput can be

20   improved where the channel is flat (by avoiding
allocation of resources to unnecessary pilots) and
maximized when the channel is dispersive (by avoiding
whole groups of sub-carriers being lost because a pilot
is not received correctly).

25   The present invention may operate by determining
the channel based on a received signal and assuming
that the transmit channel is affected similarly.

13.

In this way, the transmitted signal can be optimized (i.e. pilots allocated) based upon the signal which was just received.

Alternatively, when a signal is received, the receiver may determine the characteristics of the channel and then send back information to the transmitter to allow it to optimize future transmissions over that channel. The information may be information about the channel properties, specific pilot allocation information or other information to allow the optimum allocation of pilots for subsequent transmissions from the transmitter to be determined.

Such transmissions of information in an asymmetric channel can be in both directions to allow both receive and send links to be optimized.

The present invention can be used with sub-bands of fixed size and pilot channels allocated appropriately to provide an optimum indication of the channel or more particularly the sub-carriers within the sub-band. The pilots can then be used, for example by interpolating to determine the criteria for receiving an intermediate sub-carrier or group.

However, the present invention can also be used in conjunction with a system in which the sub-bands are dynamically allocated in response to the channel conditions. Thus, if a large number of sub-carriers are suffering flat fading then they can be allocated to

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one large sub-band and perhaps only one pilot.
Equally, where the sub-carriers are experiencing
differing fading, then they may be grouped into smaller
groups. These smaller groups would again only need one

5   pilot, which should represent the group.

In order to determine how many pilots are needed
and where they are positioned amongst the sub-carriers,
the sub-carriers are preferably grouped into groups of
sub-carriers having similar coherency. The grouping

10   means preferably allocates a sub-carrier to a group
based upon the coherency of that sub-carrier being
within a predetermined amount of that of the adjacent
sub-carriers which have already been allocated to that
group. The maximum difference in coherency is

15   preferably within 3dB of the other sub-carriers of the
group. The maximum difference in coherency is also
preferably within 0.5 degrees of the other sub-carriers
of the group. As indicated above, where dynamic
allocation of sub-bands is used, the groups can

20   correspond to the sub-bands. Where the sub-bands are
fixed, the groups may be selected and a pilot allocated
to each group regardless of the sub-banding. This may
result in two or more pilots in one sub-band or even no
pilot in some sub-bands. This appropriate information

25   for determining the characteristics of a given sub-
carrier can still be determined by interpolating
between the pilots.

15

The system preferably repeatedly monitors the coherency of the sub-carriers within a group to ensure that they continue to remain within a certain range of the other sub-carriers of the group and of the pilot

5   for that group.

The present invention provides a better estimate of the coherency of the sub-carriers and so more effective coherent demodulation can be achieved. This allows higher order modulation schemes (BPSK, QPSK,

10   8PSK etc.) to be utilized and so higher throughput can be achieved. Furthermore, sub-carriers which suffer little fading can operate with a higher modulation scheme than sub-carriers which are suffering fading.

The present invention can be implemented in a

15   conventional OFDM receiver without significant modification. Consequently, systems can easily be upgraded to operate with this improved system.

Current standards for 5GHz systems specify a fixed transmission bandwidth (20 MHz raster). However, there

20   are possible further systems which will support higher data rates through allocation of extra channels, e.g. allocating a further 20 MHz to a single link to support up to twice the maximum instantaneous data rate. For example, in the Atheros unified 5 GHz proposal, this

25   would allow up to 108 MBps user data support. The increased bandwidth of these systems means that they may be vulnerable to losing significant numbers of

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sub-carriers if a fixed pilot cannot be correctly
received. The present invention therefore allows the
full potential of these systems to be achieved under
more circumstances. The flexible allocation of pilots

5   also allows the easy implementation of variable
bandwidth systems using multi-carrier or OFDM. This
allows a maximization of throughput in a given channel
environment or a reduction in the required bandwidth
for a given throughput requirement.

10   The present invention can be implemented either in
hardware or on software in a general purpose computer.
Further, the present invention can be implemented in a
combination of hardware and software. The present
invention can also be implemented by a single

15   processing apparatus or a distributed network of
processing apparatuses. Since the present invention
can be implemented by software, the present invention
encompasses computer code provided to a general purpose
computer on any suitable carrier medium. The carrier

20   medium can comprise any storage medium such as a floppy
disk, a CD ROM, a magnetic device or a programmable
memory device, or any transient medium such as any
signal e.g. an electrical, optical or microwave signal.

          A specific embodiment of the present invention

25   will now be described in detail by reference to the
drawings, in which:-

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Brief Description of Drawings

FIG. 1 shows an overview of a typical OFDM

receiver;

FIG. 2 is a schematic diagram showing the

5   structure of a conventional adaptive antenna system;

FIG. 3 shows a representation of a system in which

the operating channel is divided into sub-bands of sub-

carriers;

FIG. 4 shows a representation of an exemplary

10   channel characteristic showing deep fading in one pilot

sub-carrier;

FIG. 5 shows a basic outline of an OFDM receiver

of the present invention;

FIG. 6 shows an outline of a dynamic pilot

15   allocation process according to the present invention;

and

FIGS. 7, 8 and 9 show enlarged views of

representations A, B and C of FIG. 6, respectively.

Best Mode for Carrying Out the Invention

20   FIG. 5 shows the functional layout of the baseband

section of an OFDM receiver used in the present

invention. Many of the functions of the receiver shown

are well known and so only a brief explanation is given

here. The received signal is quadrature (I and Q)

25   downconverted, amplified and filtered (not shown)

before being (over-) sampled by the A/D unit. The

digital over-sampled signal is then filtered and

decimated.   The over-sampling of the signal at the

start aids the digital filtering process, after which

it is then rate reduced to the required/expected sample

rate.   It is assumed in this case that the system

5   provides for a preamble of some sort in every burst

within a frame (MAC frame).   In the case of HIPERLAN,

each frame comprises a preamble portion that is made up

of three basic OFDM symbols denoted here as A, B and C.

A and B (or even C) symbols can be observed (recovered)

10   in the time domain (pre-FFT) and used to establish the

frame and frequency synchronization (as well as set the

FFT window for the data that follows these symbols)

through some correlation process.   The automatic gain

control (AGC) settings (not shown - prior to ADC) can

15   also be established.   It is possible to pass the C

symbol through as a complete symbol to the FFT.

Knowing what this symbol is in advance (and assuming

adequate synchronization), the channel variation can be

estimated on a sub-carrier basis post-FFT.   The C

20   symbol would be 'switched' out to estimate the channel

compensation (rotation of the symbols in the sub-

carriers).   However, this same channel estimation could

be used in the sub-carrier grouping procedure.

Alternatively, pilots can be selected post-FFT and

25   used to estimate the channel over time.   The pilots

have known symbols in them and are processed to

identify what symbol is received (I' and Q') and what

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symbol was expected (I and Q). If I' $\neq$ I and Q' $\neq$ Q then you can calculate the phase rotation and amplitude change required to make them equal. The pilots provide estimates of these values so that it is possible to

5   estimate or interpolate the amplitude and phase rotation required for all the intermediate sub-carriers. This is known as a one-tap equalization, which is a simple if not crude way to determine the correction, needed for all the channels. The

10   determined value of the sub-carrier's amplitude and rotation (I and Q) correction value can then be applied. The remainder of the system carries out the unpacking and unscrambling of the data to the relevant bits.

15   It should be noted that the preamble symbols are there for 'training' or synchronization purposes i.e. they are known at the receiver so that it can form an estimate of the influences of the channel for an equalizer or even smart antenna weight calculation.

20   The basic operation of the receiver system will now be described with reference to FIGS. 6 to 9. Data is transmitted in blocks of data known as symbols. These symbols typically comprise a guard interval for reducing inter-symbol interference as well as a useful

25   data part. Each symbol is transmitted on a sub-channel using the sub-carriers referred to above. The data to be transmitted is divided up into symbols, which are

20

then sent on each of the sub-channels and re-
constructed at the receiver. In addition, the series
of symbols transmitted generally include one or more
preamble symbols, as indicated above, for providing
5   control and synchronization information etc.

In this example, communication is taking place
between two transceivers TRX1 and TRX2. This could be
terminal and base station in a mobile communication
system or two terminals in a wireless LAN etc.
10   Initially, a signal would be transmitted by TRX1 in a
known format to the receiver TRX2. This format allows
the receiver to decode the various aspects of the
message, which are important to the basic operation of
the connection across an unknown channel, e.g. a
15   broadcast message or other training burst. The
receiver TRX2 uses the format of this message (signal
characteristics, preamble, etc.) to determine the state
of the channel and estimate the coherence bandwidth.
The receiver thus determines an estimate of the
20   variation of the fading across the entire band (such as
that shown in FIG. 4) using the preamble symbol, in the
frequency domain. An estimate of the band is obtained
in quadrature (I and Q) information. The 'flatness' of
the received power across the sub-carriers and phase
25   differences can be obtained.

It may also be possible to estimate the coherence
time of the channel and use this to estimate the time

until the determined pilot scheme will need to be
modified. Where the channel characteristics are
changing rapidly, it will be necessary to re-asses the
pilot allocations more often than if the

5   characteristics are stable of a relatively long period
of time.

From the estimate, the receiver divides the sub-
carriers across the band into groups of sub-carriers.
The sub-carriers are grouped with other sub-carriers

10   that are within a certain range of each other. The
received power and phase differences do not have to be
absolutely equal but just sufficiently close to be
within a certain range. The range may be varied
depending upon the circumstances. By making the range

15   small, the groups of sub-carriers will be small but
very coherent. In contrast, if the range is large, the
groups can be much larger but they would generally be
less coherent. The range is therefore selected
according the available processing power, required

20   reception quality and so on. If there are a lot of
small groups and a pilot is allocated to each group,
then the data throughput may be reduced because a large
portion of the transmitted data would be allocated to
pilots and the pilots do not carry user data.

25   A typical value for the range could be that if
sub-carriers are within 3dB of received power and
0.5 degrees of variation.

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The pilots are then allocated by selecting one of the sub-carriers within a determined group. The pilot may be selected as the most representative of the other sub-carriers or more simply as the central one of the

5   group or one of the edge members of the group.

TRX2 then utilizes the determined pilot scheme to transmit data back to TRX1. This assumes that the transmission takes place within the determined coherency time. As the system helps to ensure more

10   reliable estimation of the coherency, TRX2 may now be able to transmit using a higher order modulation scheme on some sub-carriers than was possible if a fixed pilot scheme was being used. This allows greater data throughput in some or all of the sub-carriers.

15   TRX1 receives the signal from TRX2 in the new format. The location of the pilots can be determined in TRX1 in a number of ways. The location of the pilots can be signaled through a robust channel message, e.g. coded using BCH. Alternatively, an

20   indication that the pilot channels have been moved could be sent and a blind estimation carried out by TRX1. This does involve a degree of latency at TRX1 but is suitable for non time critical data or where there is a high processing capability. For example,

25   the allocation of the pilots by using knowledge of the pilot channel content e.g. through a correlation or matched filter process in the frequency domain of the

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receiver, higher order statistical analysis, etc.

Once both TRX1 and TRX2 are aware of the pilot
allocation, communication can proceed as normal. The
coherency of the groups is periodically monitored to
5   ensure that they remain within predetermined limits.
The coherency may be checked to ensure that the members
of the group are still within the range of values used
to determine the groups initially and also that the
selected pilots are still appropriate. Alternatively,
10   the range may be slightly larger to allow some decrease
in the coherency (to avoid a very small reduction in
coherency precipitating a complete re-assessment of the
groupings). If the coherency of any of the sub-
carriers in a group is below a predetermined level,
15   then all the groups are re-assessed as above and the
sub-carriers reallocated to a new set of groups. If
the representative pilot sub-carrier of a group is no
longer representative then the pilot might be re-
assessed or all the groups may be re-assessed.
20   Alternatively, rather than re-assess all the groups, if
only one group is out of range or one pilot is no
longer representative of the group, then it may be
possible to divide only that group into two or more new
groups which in themselves are sufficiently coherent.
25   Then new pilots can be allocated to each new group.
Although this increases the number of groups, that may
be acceptable as an interim measure to avoid having to

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re-assess all of the groups.

The number of pilots is variable but it is clearly desirable to provide enough pilots to allow reliable coherent demodulation of the data given a channel dispersion/fading estimate. Equally the number of pilots should not be excessive so that throughput of user data on the remaining sub-carriers is adversely affected despite the possibility of utilizing higher modulation schemes.

The arrangement described above assumes that the channel is reciprocal, i.e. the channel is affected similarly in both directions of transmission. However, this may no be the case. Under such circumstances, the determined pilot allocation scheme may be optimized for transmission from TRX1 to TRX2 but not be optimum for transmission from TRX2 to TRX1. Therefore, the present invention also provides for a system where teach of the terminals TRX1, TRX2 have a separate pilot allocation scheme for transmission to them. This means that after transmitting a test signal, the receiver must transmit back information about the channel or optimum pilot allocation scheme (see above) to the transmitter for future transmissions. In addition, it is necessary for the respective receiver to monitor the performance of the selected allocation scheme to determine whether or not it should be maintained.

The above described system, indicates that pilots

25

are selected on the basis of groups of sub-carriers of
similar coherency. However, the pilots may dynamically
allocated in some other way to accommodate limitations
in processing performance or efficiency of transmitting

5   pilot information for example. For example, the total
number of pilots may be specified and the pilots may be
allocated uniformly across the band.

These systems are intended to cover operation over
relatively large overall bandwidths. For example,

10   HIPERLAN may operate in the bands 5.15 to 5.35 GHz and
5.47 to 5.725 GHz, so with both these bands it may
arise that the channel is extended. However, one set
of sub-carriers may be a long way off the next set, in
frequency. Consequently, when the groups are being

15   determined it may be necessary to apply some bounding
conditions. This avoids the system trying to group
together spectrally disparate sub-carriers.

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C L A I M S

1. A terminal for use with a multi-carrier communication system, the terminal comprising:

a pilot allocator for determining pilot allocation information based upon the characteristics of a channel over which a signal is to be transmitted; and

a transmitter for transmitting a multi-carrier signal comprising a plurality of sub-carriers wherein one or more of the sub-carriers are allocated as pilot channels based upon said pilot allocation information.

2. A terminal according to claim 1 further comprising a receiver for receiving the pilot allocation information from another terminal to which a transmission was previously made.

3. A terminal according to claim 2 wherein the receiver is adapted to extract the pilot allocation information from signal data received from said other terminal.

4. A terminal according to claim 2 wherein the receiver analyses the signal received from said other terminal to determine which of the received sub-carriers are allocated as pilots to determine the pilot allocation information.

5. A terminal according to claim 1 further comprising:

a receiver for receiving a signal transmitted over said channel; and

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an analyzer for analyzing the received signal to
determine the characteristics of the transmission
channel for use by said pilot allocator.

6. A terminal for use with a multi-carrier
communication system, the terminal comprising:

a receiver for receiving a multi-carrier signal
comprising a plurality of sub-carriers transmitted over
a channel;

an analyzer for analyzing the received signal to
determine the channel characteristics; and

a pilot allocator for using the channel
characteristics to determine pilot allocation
information identifying one or more of the sub-carriers
to be allocated as pilot channels.

7. A terminal according to claim 6 further
comprising a transmitter for transmitting a multi-
carrier signal wherein one or more of the sub-carriers
are allocated as pilot channels based upon said pilot
allocation information.

8. A terminal according to claim 6 or 7 wherein
said multi-carrier signal includes signal data
representing said pilot allocation information.

9. A terminal according to claim 5 or 6 wherein
said pilot allocator includes a group selector for
allocating each sub-carrier to one of a plurality of
groups of sub-carriers and allocating one sub-carrier
in each of said groups as a pilot sub-carrier.

10. A terminal according to claim 9 wherein said group selector is adapted to allocate a sub-carrier to a group based upon the coherency of the sub-carrier.

11. A terminal according to claim 9 or 10 wherein said group selector determines the coherency of each sub-channel.

12. A terminal according to any one of claims 9 to 11 further comprising a controller for controlling the group selector to establish the coherency of the sub-channels of the sub-bands to determine that the difference between the coherency of the pilot sub-carrier and the other sub-carriers of the group is below a predetermined amount.

13. A terminal according to claim 12 wherein the controller is adapted to re-assign the sub-channels in at least that group to new groups and determine a new pilot sub-channel to said new groups if it is determined that the difference between the coherency of the pilot sub-carrier and the other sub-carriers of the group is below a predetermined amount.

14. A terminal according to claims 12 or 13 wherein the coherency measurement is based upon received power and/or phase difference.

15. A terminal according to any one of claims 12 to 14 wherein the first predetermined amount is 3dB for the received power and/or 0.5 degrees for the phase difference.

16. A method of communication in a multi-carrier communication system comprising:

determining pilot allocation information based upon the characteristics of a channel over which a

5 signal is to be transmitted; and

transmitting a multi-carrier signal comprising a plurality of sub-carriers wherein one or more of the sub-carriers are allocated as pilot channels based upon said pilot allocation information.

10 17. A method according to claim 16 further comprising receiving the pilot allocation information from another terminal to which a transmission was previously made.

18. A method according to claim 17 wherein the

15 pilot allocation information is extracted from signal data received from said other terminal.

19. A method according to claim 17 further comprising analyzing the signal received from said other terminal to determine which of the received sub-

20 carriers are allocated as pilots in order to obtain the pilot allocation information.

20. A method according to claim 16 further comprising:

receiving a signal transmitted over said channel;

25 and

analyzing the received signal to determine the transmission channel characteristics.

21. A method of communication in a multi-carrier
communication system comprising:

receiving a multi-carrier signal comprising a
plurality of sub-carriers transmitted over a channel;

5   analyzing the received signal to determine the
channel characteristics; and

using the channel characteristics to determine
pilot allocation information identifying one or more of
the sub-carriers to be allocated as pilot channels.

10   22. A method according to claim 21 further
comprising transmitting a multi-carrier signal wherein
one or more of the sub-carriers are allocated as pilot
channels based upon said pilot allocation information.

23. A method according to claim 21 or 22 wherein
15 said multi-carrier signal includes signal data
representing said pilot allocation information.

24. A method according to any one of claims 20 or
21 wherein determining said pilot allocation
information includes:

20   allocating each sub-carrier to one of a plurality
of groups of sub-carriers; and

allocating one sub-carrier in each of said groups
as a pilot sub-carrier.

25. A method according to claim 24 wherein each
25 sub-carrier is allocated to a group based upon the
coherency of the sub-carrier.

26. A method according to claims 24 or 25 wherein

the coherency of each sub-channel is determined.

27. A method according to any one of claims 24 to 26 further comprising checking the coherency of the sub-channels of the sub-bands to that the difference between the coherency of the pilot sub-carrier and the other sub-carriers of the group is below a predetermined amount.

28. A method according to claim 27 wherein if it is determined that the difference between the coherency of the pilot sub-carrier and the other sub-carriers of the group is below a predetermined amount, the sub-channels in at least that group are re-assigned to new groups and new pilot sub-channel are determined for said new groups.

29. A method according to claims 27 or 28 wherein the coherency measurement is based upon received power and/or phase difference.

30. A method according to any one of claims 27 to 29 wherein the first predetermined amount is 3dB for the received power and/or 0.5 degrees for the phase difference.

31. A method of processing a received broadband signal substantially as described herein with reference to the accompanying drawings.

32. A carrier medium carrying computer readable instructions for controlling a computer to carry out the method of any one claims 16 to 31.
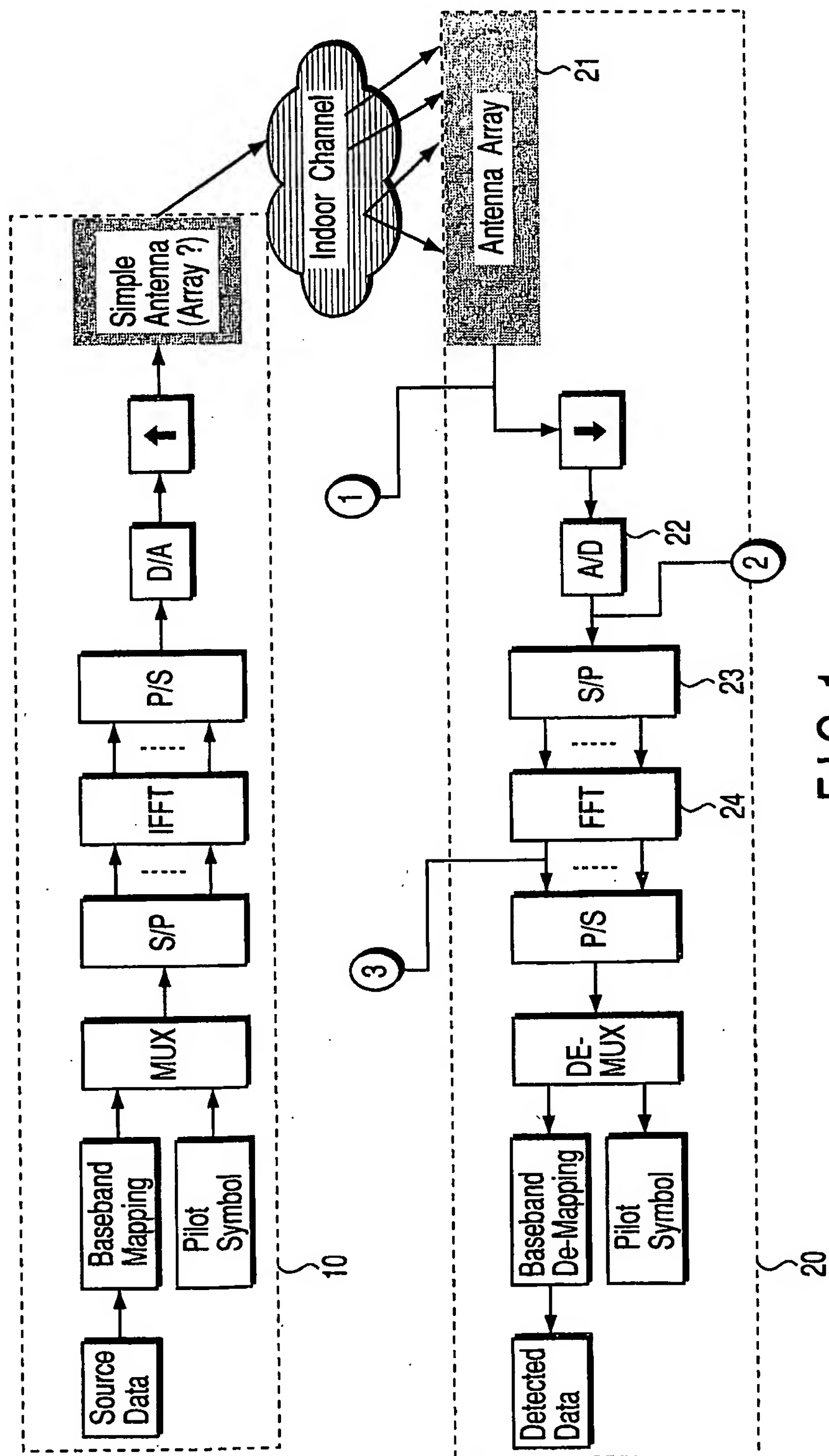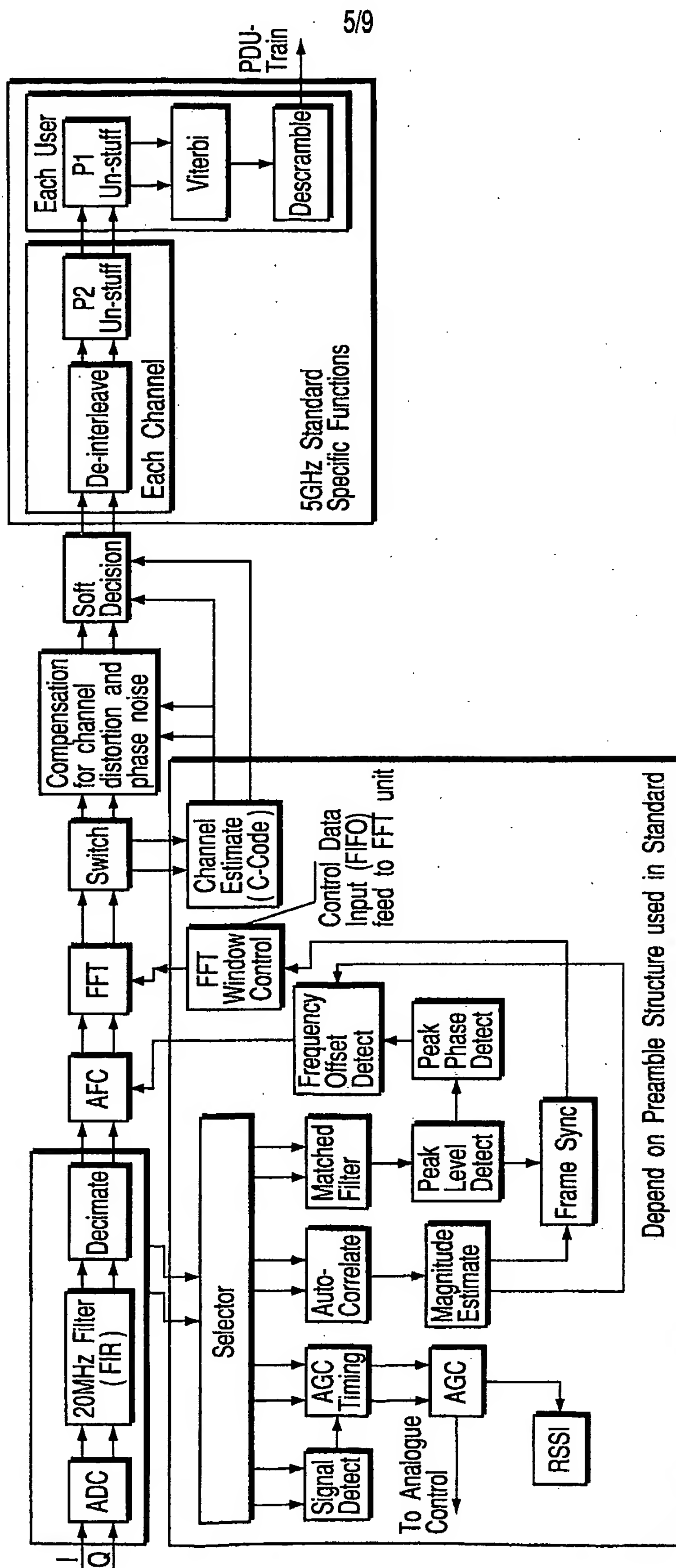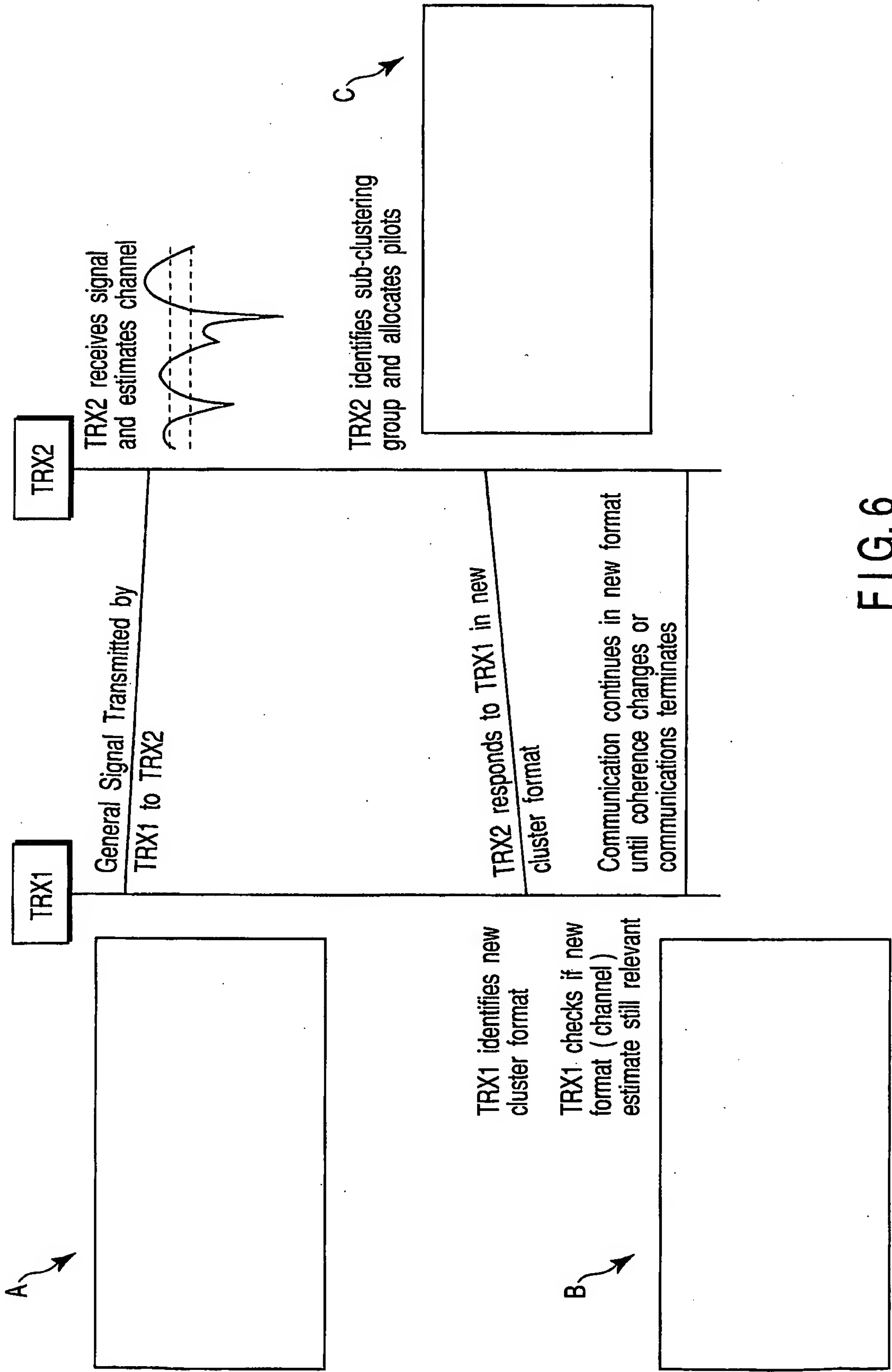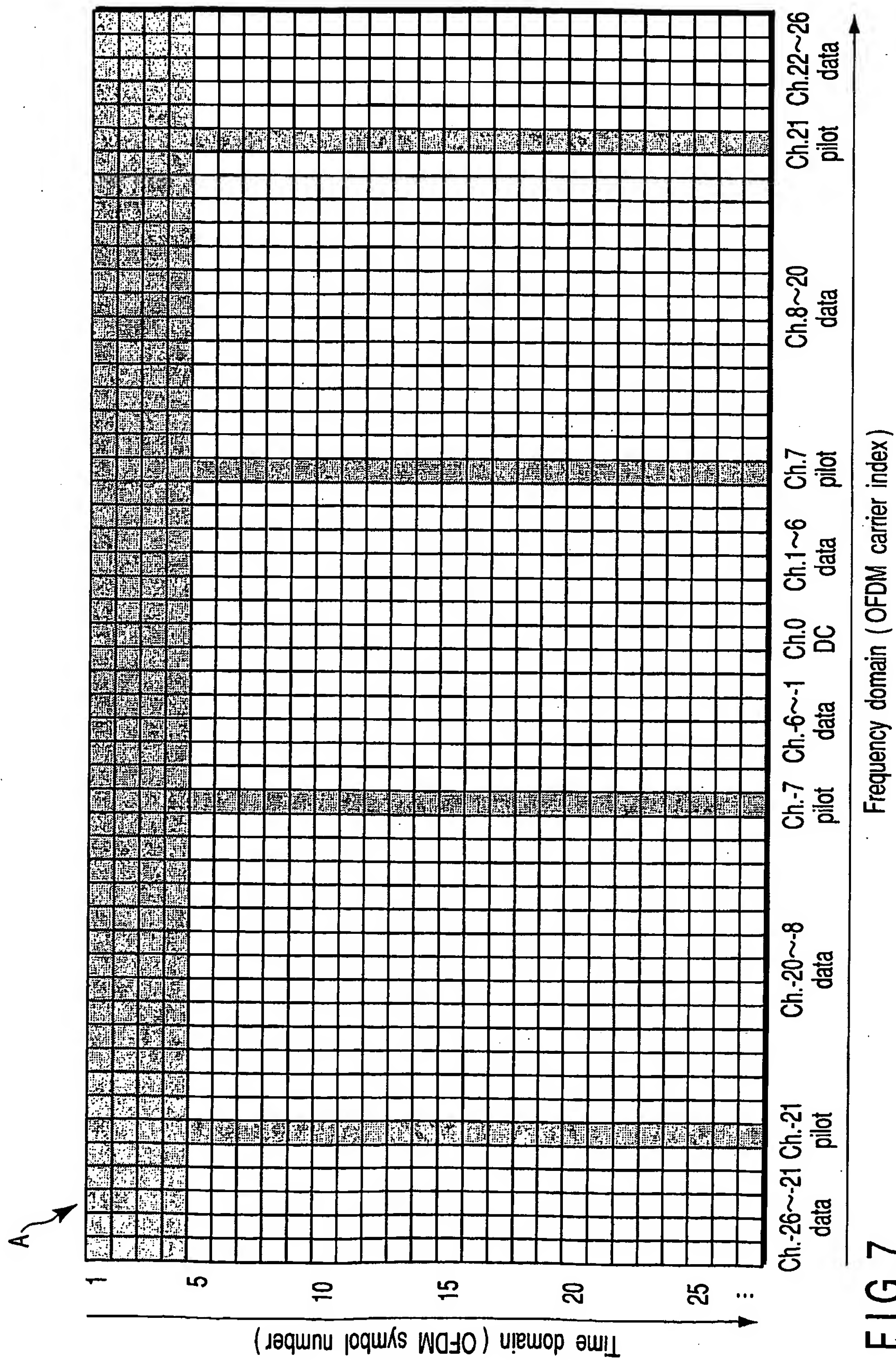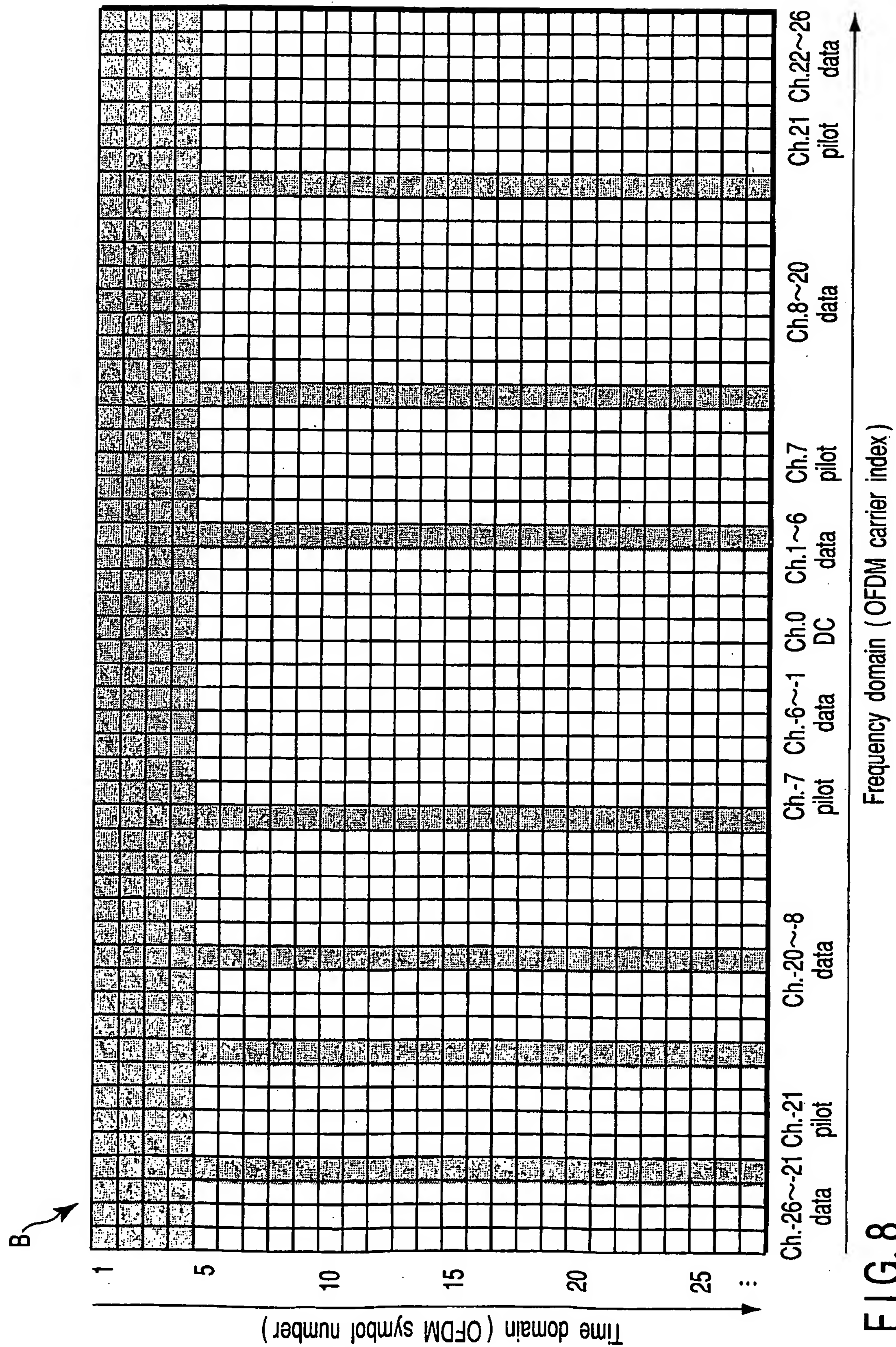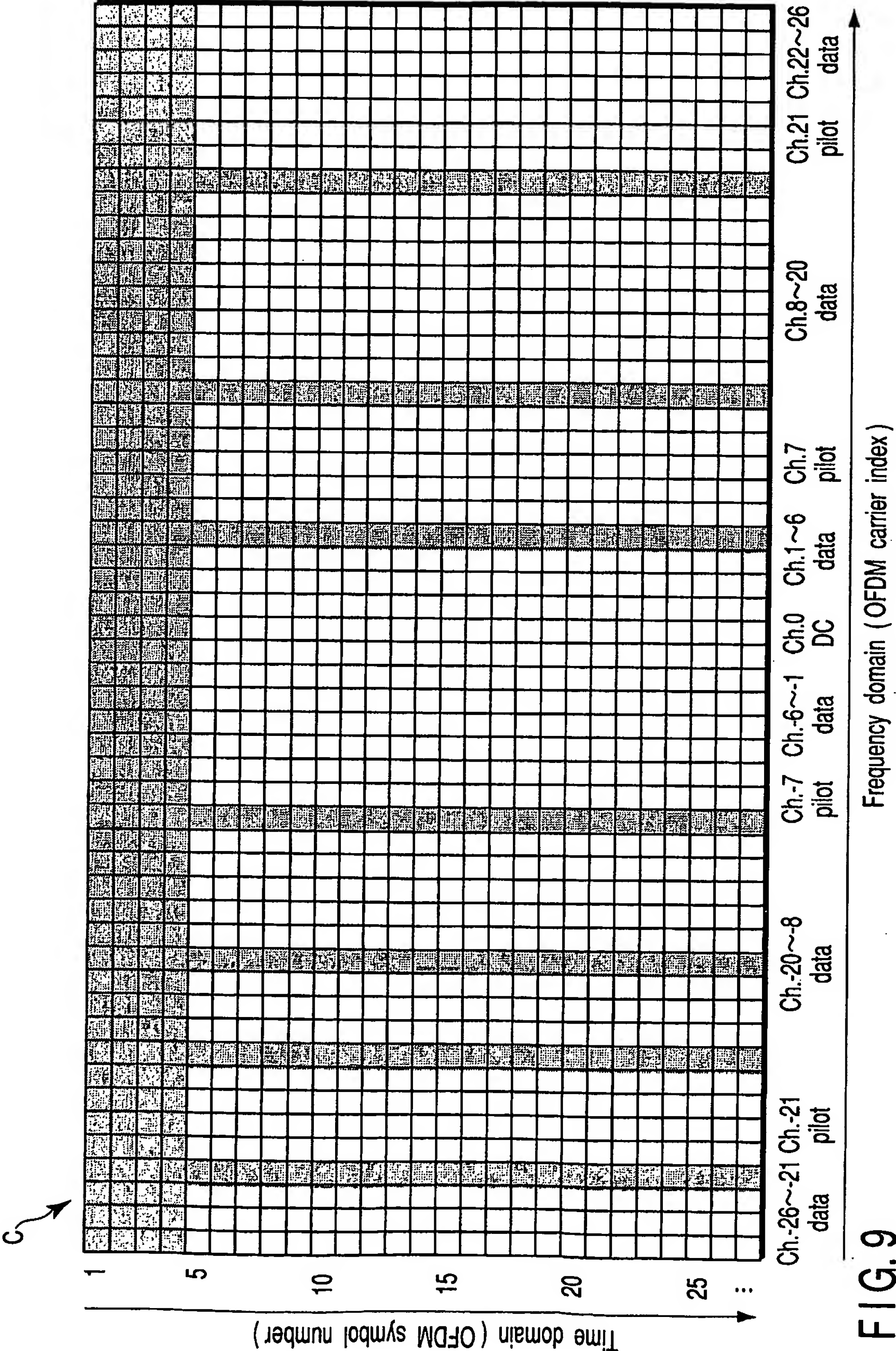
FIG.1

FIG. 2
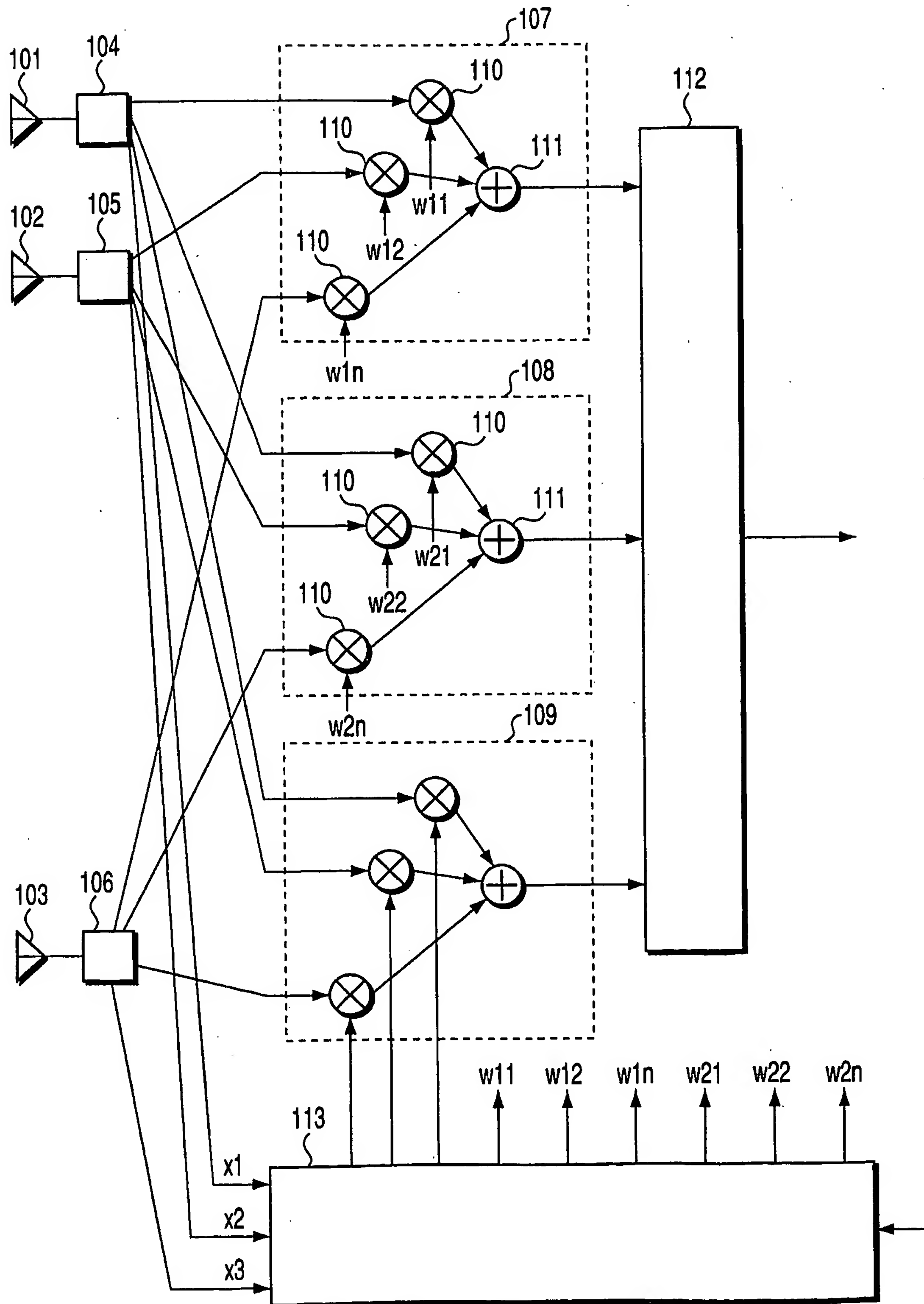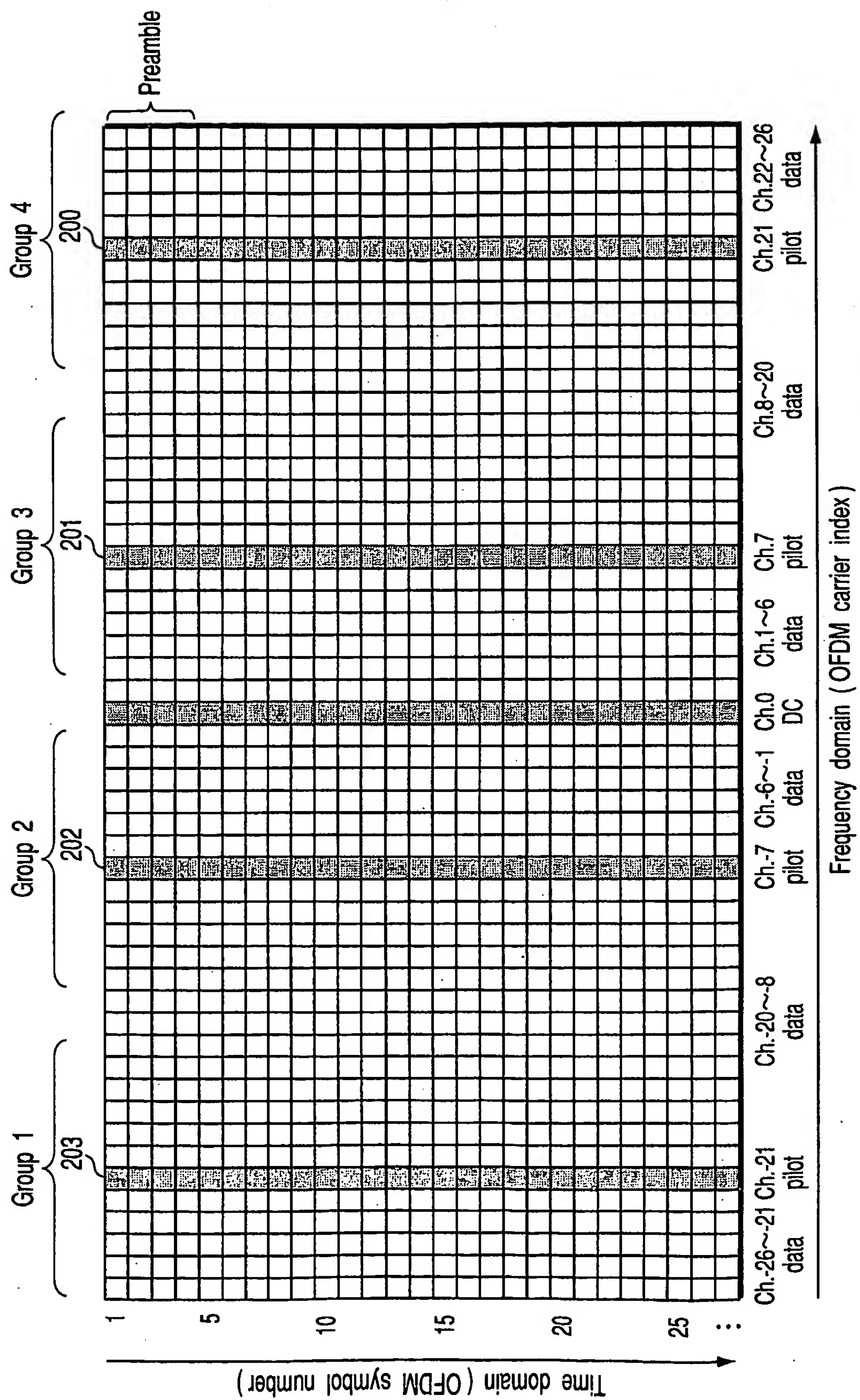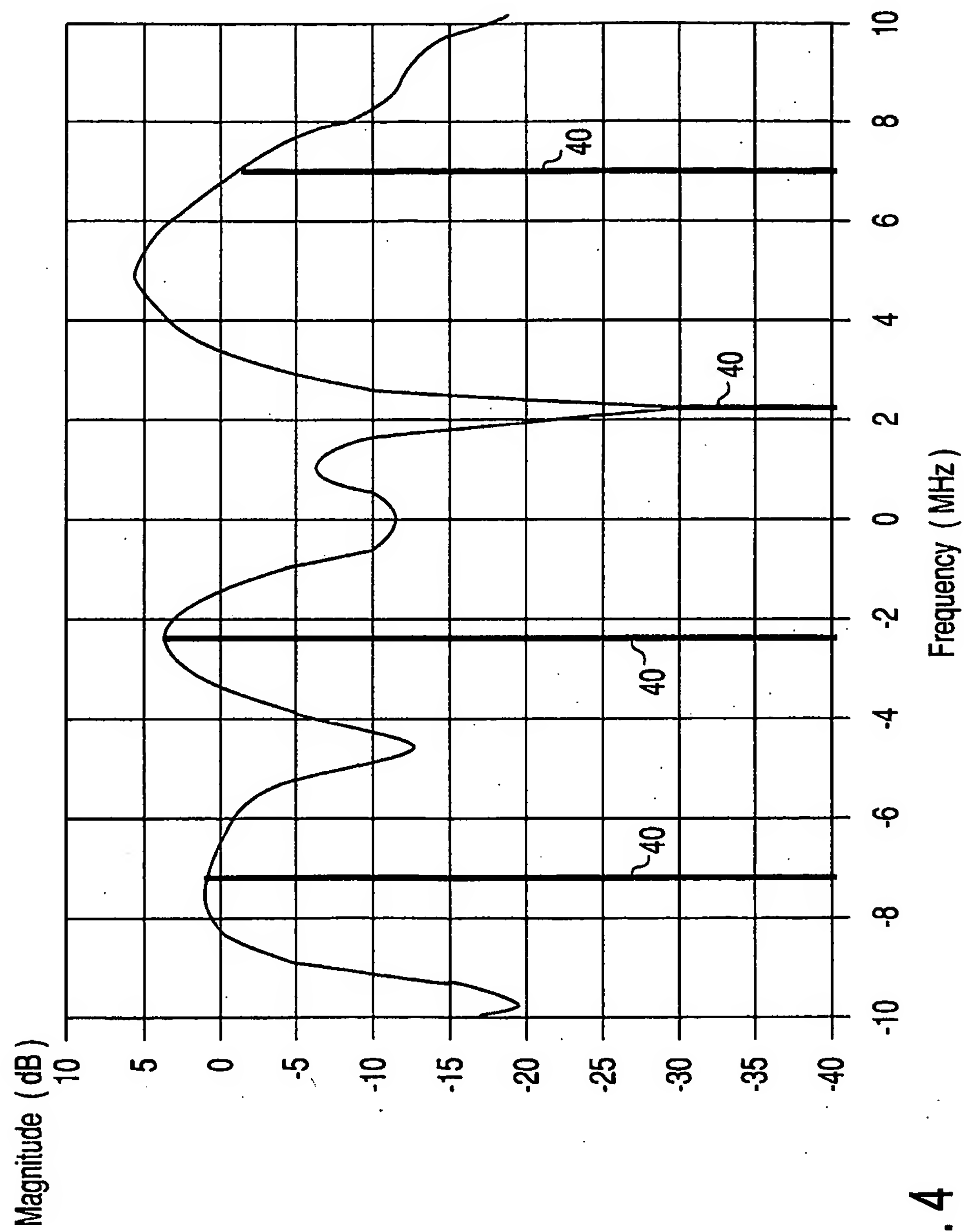
F I G. 3

FIG. 4

F I G. 5

TRX2

C

TRX2 receives signal and estimates channel

TRX2 identifies sub-clustering group and allocates pilots

General Signal Transmitted by TRX1 to TRX2

TRX2 responds to TRX1 in new cluster format

Communication continues in new format until coherence changes or communications terminates

TRX1

TRX1 identifies new cluster format

TRX1 checks if new format (channel) estimate still relevant

A

B

F I G. 6

F I G. 7

FIG. 8

FIG.9

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L27/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 785 645 A (ALCATEL BELL NV) 23 July 1997 (1997-07-23) the whole document	1-9, 16-24, 31,32
A		10-15, 25-30
A	EP 1 083 719 A (SONY CORP) 14 March 2001 (2001-03-14) abstract claims 1-33	1-32

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
15 July 2003	23/07/2003

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Reilly, D |

Form PCT/ISA/210 (second sheet) (July 1992)

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Information on patent family members

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